

Technology Readiness Level Calculator

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What Is the TRL Calculator?

Introduction

TRL Definitions

Software TRLs

Calculator

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- **Tool for applying NASA's Technology Readiness Levels (TRLs) to technology development programs**
- **Microsoft Excel spreadsheet application**
 - **Standard set of questions about the program**
 - **Graphically displays TRL achieved**
- **Provides repeatable system for measuring a technology's maturity**
 - **"Snap shot" of program maturity at a given time**
 - **Historical picture of what's been done so far**
- **TRLs are a uni-dimensional scale used to provide a measure of technology maturity**



WHY USE TRLs?

Introduction

TRL Definitions

Software TRLs

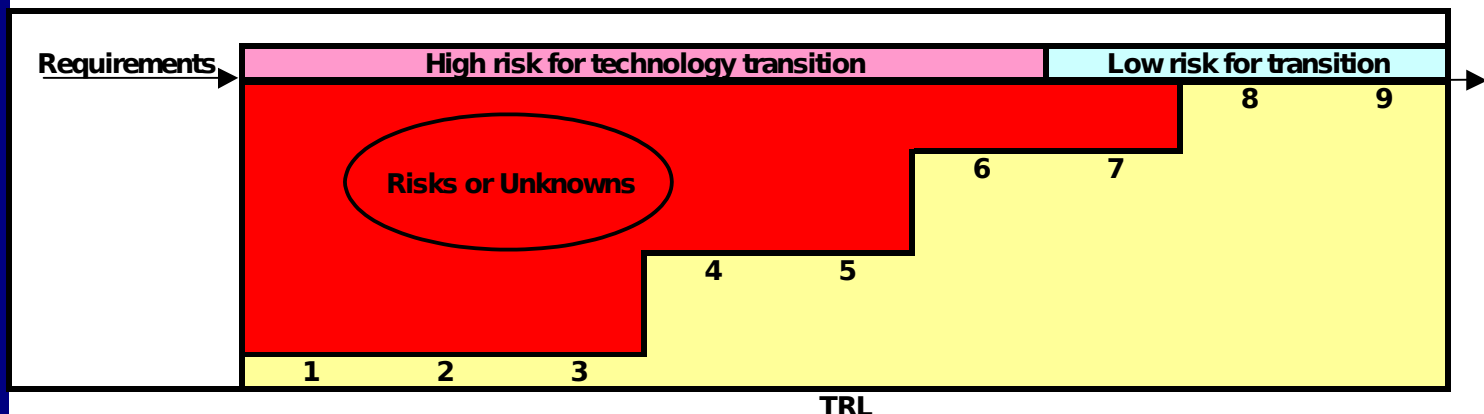
Calculator

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- Invented in the mid 70's (Sadin) to assist the NASA new technology development process and to provide a communication tool between technologists and managers
- To Provide A Common Understanding of Science and Technology Exit Criteria and As A Risk Management Tool
- GAO "Maturity of Technology at Program Start Is An Important Determinant of Success"

Using TRLs to Control Risk of Technology Transition

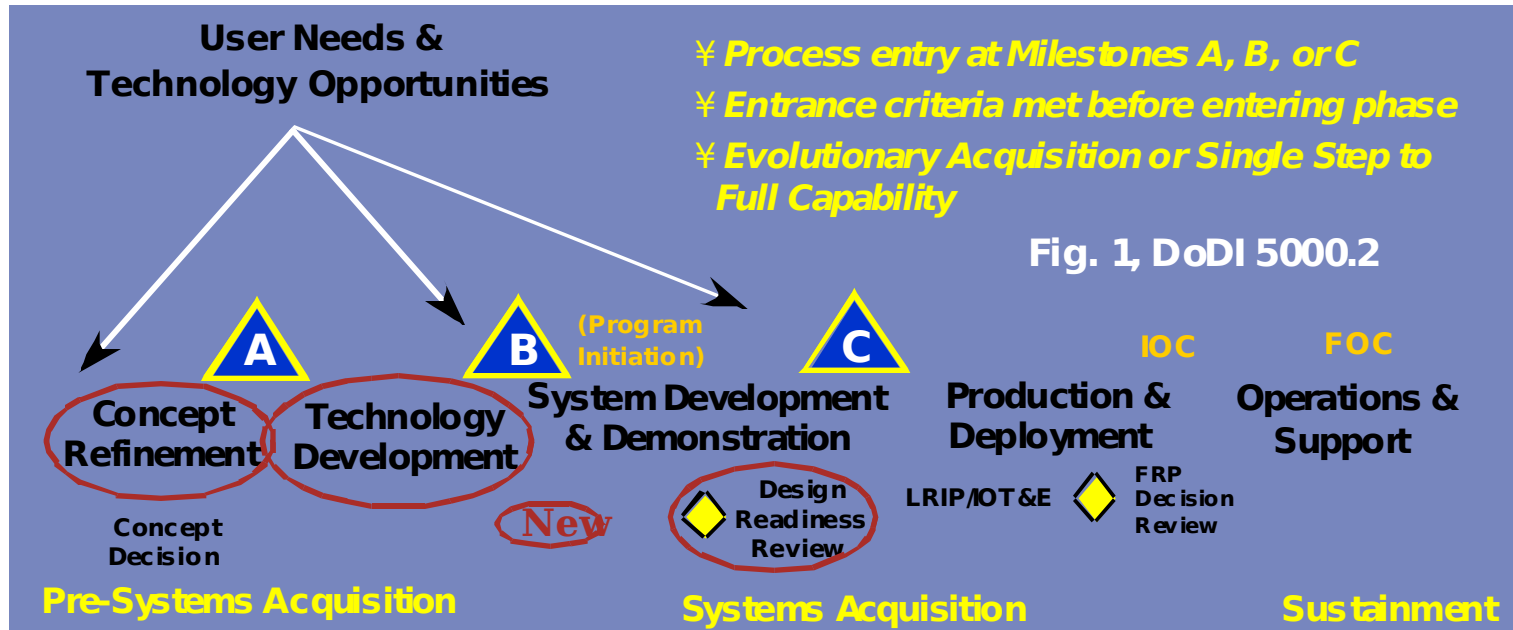




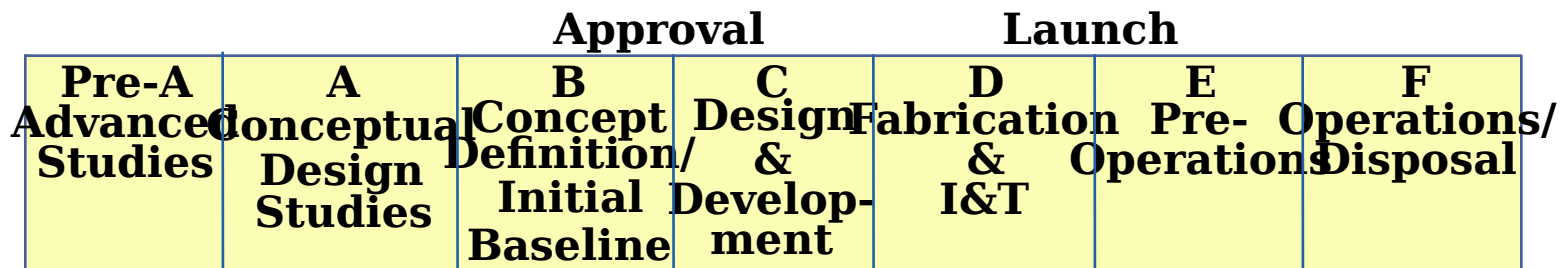
DoD & NASA Life Cycle



DoD Project Life Cycle



Traditional NASA Project Cycle





Historic TRL Definitions



Introduction TRL Definitions Software TRLs Calculator Issues Conclusion	TRL Definitions from 1989 (Sadin, et. al.)	
	Level1	Basic Principles Observed And Reported
	Level2	Potential Application Validated
	Level3	Proof Of Concept Demonstrated, Analytically And/Or Experimentally
	Level4	Component And/Or Breadboard Laboratory Validated
	Level5	Component And/Or Breadboard Validated In Simulated Or Real-space Environment
	Level6	System Adequacy Validated In Simulated Environment
	Level7	System Adequacy Validated In Space
Current definitions are similar with new 8 and 9 added to carry TRL concept through mission operations.		



TRL Definitions

DoD Interim Guidance



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DoD definitions are closely derived from NASA (Mankins '95) (NASA terms are in parentheses)	
Level1	Basic principles observed and reported
Level2	Technology concept and/or application formulated
Level3	Analytical and experimental critical function and/or characteristic proof of concept
Level4	Component and/or breadboard validation in laboratory environment
Level5	Component and/or breadboard validation in relevant environment
Level6	System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
Level7	System prototype demonstration in an operational (space) environment
Level8	Actual system completed and (flight) qualified through test and demonstration (Ground and Space)
Level9	Actual system (flight) proven through successful mission operations



TRL Descriptions Hardware & Software



Introduction TRL Definitions Software TRLs Calculator Issues Conclusion	Leve l1	Lowest level of technology readiness. Research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
	Leve l2	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
	Leve l3	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
	Leve l4	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
	Leve l5	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
	Leve l6	Representative model or prototype system, which is well beyond that of TRL5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
	Leve l7	Prototype near or at planned operational system. Represents a major step up from TRL6, requiring demonstration of an actual system prototype in an operational environment, such as in aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
	Leve l8	Technology proven to work in its final form and under expected conditions. In most cases, this TRL represents the end of true system development. Examples7 include developmental test and evaluation of the system in its intended weapon system to determine if it meets specifications.



Need for Process



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From Graettinger, et. al. 2002

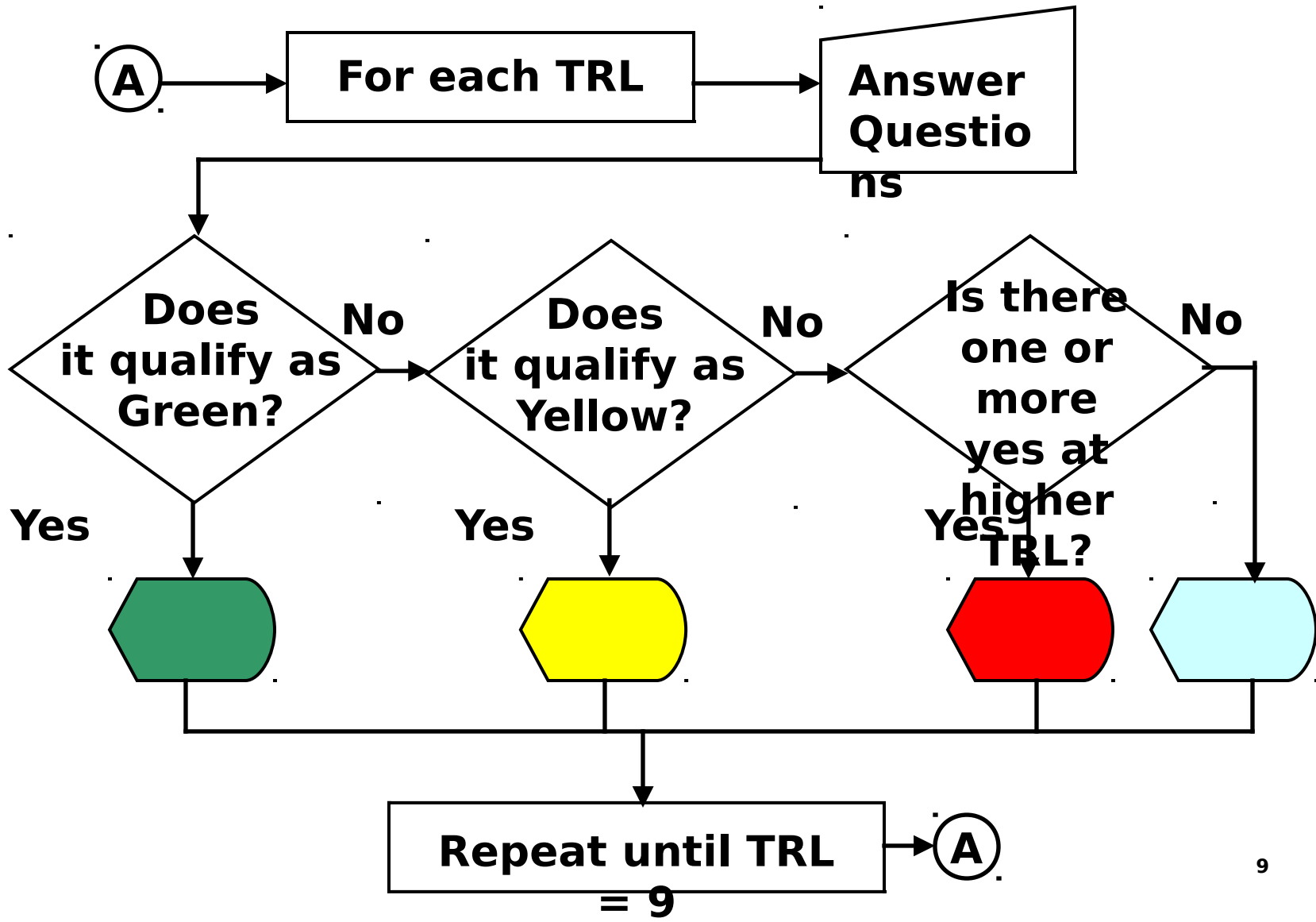
- **“Consistent DoD guidance on how to assess TRLs is lacking,...”**
- **“Thus, TRLs are meant to be overarching definitions for any technology, while interpretations or amplifications for specific technologies are left to the experts in that technology domain.”**
- **“Currently, there is no standard or commonly used approach for implementing TRLs.”**
- **Consequently, a process is needed that improves consistency (reliability) and efficiency of the application of TRLs**



Decision Process Flowchart



- Introduction
- TRL Definitions
- Software TRLs
- Calculator
- Summary



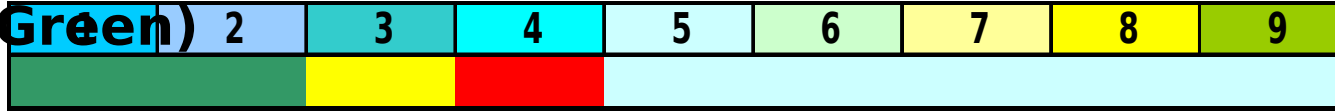


Calculator Features



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Horizontal display shows TRL achieved (Red, Yellow, Green)

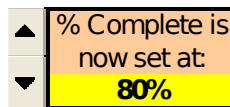


Green and Yellow TRL achieved displayed



Questions can be answered by check box or % complete slider

% Complete		Level of Knowledge (Check all that apply)	
◀▶	15	☒	Basic scientific principles observed
◀▶	15	☐	Possible application exists
◀▶	85	☐	Paper studies confirm basic principles
◀▶	85	☐	Paper studies show that application is feasible



User can set point where % complete is counted

Some questions answered with “radio buttons”

Components (Pick the best answer)	
☒	No system components, just basic laboratory research equipment to verify physical principles
☐	Ad hoc and available laboratory components are surrogates for system components



TRL Calculator

S&T Program in Early Development



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TRL Calculator Main Menu**Read TRL Documentation****PRT Calculator**

Hardware TRL Calculator v 1.12

▲

▼

% Complete is now set at:
80%

Technology Readiness Level Achieved									Weighted TRL
1	2	3	4	5	6	7	8	9	

% Complete	Level of Knowledge (Check all that apply or use slider for % complete)										
◀ ▶	☒	Basic scientific principles observed									
◀ ▶	☒	Possible application exists									
◀ ▶	☒	Paper studies confirm basic principles									
◀ ▶	☐	Paper studies show that application is feasible									Wgt
◀ ▶	☐	Physical laboratory experimental evidence confirms basic principles									0
◀ ▶	☐	Laboratory experiments verify feasibility of application									TRL 1
◀ ▶	☐	Rigorous analytical studies confirm basic principles									
◀ ▶	☐	Physics underlying the technology is well understood									
◀ ▶	☐	Overall system requirements for end user's application are known									
◀ ▶	☐	Science known to extent that mathematical and/or computer models and simulations are possible									
◀ ▶	☐	System interface requirements known									
◀ ▶	☐	Operating environment for eventual system known									

Components (Pick the best answer)		
☒	No system components, just basic laboratory research equipment to verify physical principles	
☐	Ad hoc and available laboratory components are surrogates for system components	
☐	Some special purpose components combined with available laboratory components	
☐	Components are functionally compatible with operational system	Wgt
☐	Components are representative of production components	0
☐	Components are form, fit, and function compatible with operational system	TRL 3



TRL Calculator

S&T Program Ready to Transition



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Read TRL Documentation

PRT Calculator

Hardware TRL Calculator v 1.12

▲ % Complete is
now set at:
▼ **80%**

Technology Readiness Level Achieved									Weighted TRL
1	2	3	4	5	6	7	8	9	

% Complete		Level of Knowledge (Check all that apply or use slider for % complete)											
◀	▶	☒	Basic scientific principles observed										
◀	▶	☒	Possible application exists										
◀	▶	☒	Paper studies confirm basic principles										
◀	▶	☒	Paper studies show that application is feasible										Wgt
◀	▶	☒	Physical laboratory experimental evidence confirms basic principles										0
◀	▶	☒	Laboratory experiments verify feasibility of application										TRL 6
◀	▶	☒	Rigorous analytical studies confirm basic principles										
◀	▶	☒	Physics underlying the technology is well understood										
◀	▶	☒	Overall system requirements for end user's application are known										
◀	▶	☒	Science known to extent that mathematical and/or computer models and simulations are possible										
◀	▶	☒	System interface requirements known										
◀	▶	☒	Operating environment for eventual system known										

Components (Pick the best answer)		
☐	No system components, just basic laboratory research equipment to verify physical principles	
☐	Ad hoc and available laboratory components are surrogates for system components	
☐	Some special purpose components combined with available laboratory components	
☒	Components are functionally compatible with operational system	Wgt
☐	Components are representative of production components	0
☐	Components are form, fit, and function compatible with operational system	TRL 6



Issues

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- **Separate Versions for Hardware and Software**
- **Technology Maturity vs. Programmatics**
 - **Pure Program Issues Measured Separately**
- **TRL Is One Dimension of Technology Maturity**
 - **Measuring Technology Maturity Is a Multi-Dimensional Problem**
- **Producibility - Manufacturing Readiness Levels**
- **Practice Based Technology Maturity**
 - **Emphasis on Community of Users**
- **If Goal Is Transition, Process Requires Both Technology Developer and Technology Receiver**
 - **Readiness to Receive Is a Separate Measure**
- **Statistical Validity of Calculator Not Yet Demonstrated**



Scaling From Psychometrics



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- **The field of Psychometrics from Psychology provides a scientific method for creating and applying “scales”**
- **“Scaling is the branch of measurement that involves the construction of an instrument that associates qualitative constructs with quantitative metric units. Scaling evolved out of efforts in psychology and education to measure “unmeasurable” constructs like authoritarianism and self esteem. In many ways, scaling remains one of the most arcane and misunderstood aspects of social research measurement. And, it attempts to do one of the most difficult of research tasks -- measure abstract concepts.”**
Trochim
- **Professor Trochim, Cornell University “The science of Psychometrics will improve our TRL process”**
- **Professor Gonzalez, U. Mich “It would be ideal to redefine categories. The other approach is a decision aid, a piece of software that asks questions and hones in on the category.”**



What is Scaling?

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- **“Scaling is the assignment of objects to numbers according to a rule.” S. S. Stevens**
- **Scaling starts with a “focus” followed by a large (>100 preferred) set of statements related to the focus. (see <http://trochim.human.cornell.edu> for examples)**
- **Statements are then rated by participants (or judges)**
- **Results are analyzed and a scale is created.**
- **There are three techniques used**
- **Thurstone or Equal-Appearing Interval Scaling, Likert or "Summative" Scaling, and Guttman or "Cumulative" Scaling.**
- **A tool is then created that allows users to respond to questions and an algorithm is used to calculate the result on the scale**
- **The TRL Calculator represents an ad hoc version of the Psychometric scaling process**



Conclusion

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- **AFRL Developed a TRL Calculator for Hardware and Software**
- **Calculator Simplifies the Process of Applying TRLs to Research and Development Programs**
- **Next Steps**
 - **Develop Final Set of Software Descriptions**
 - **Add Questions for Manufacturing Readiness**
 - **Add Questions for Practice Based Technologies**
 - **Formal Validation of TRL Calculator Using Psychometrics or Similar Statistical Technique**



Discussion / Questions



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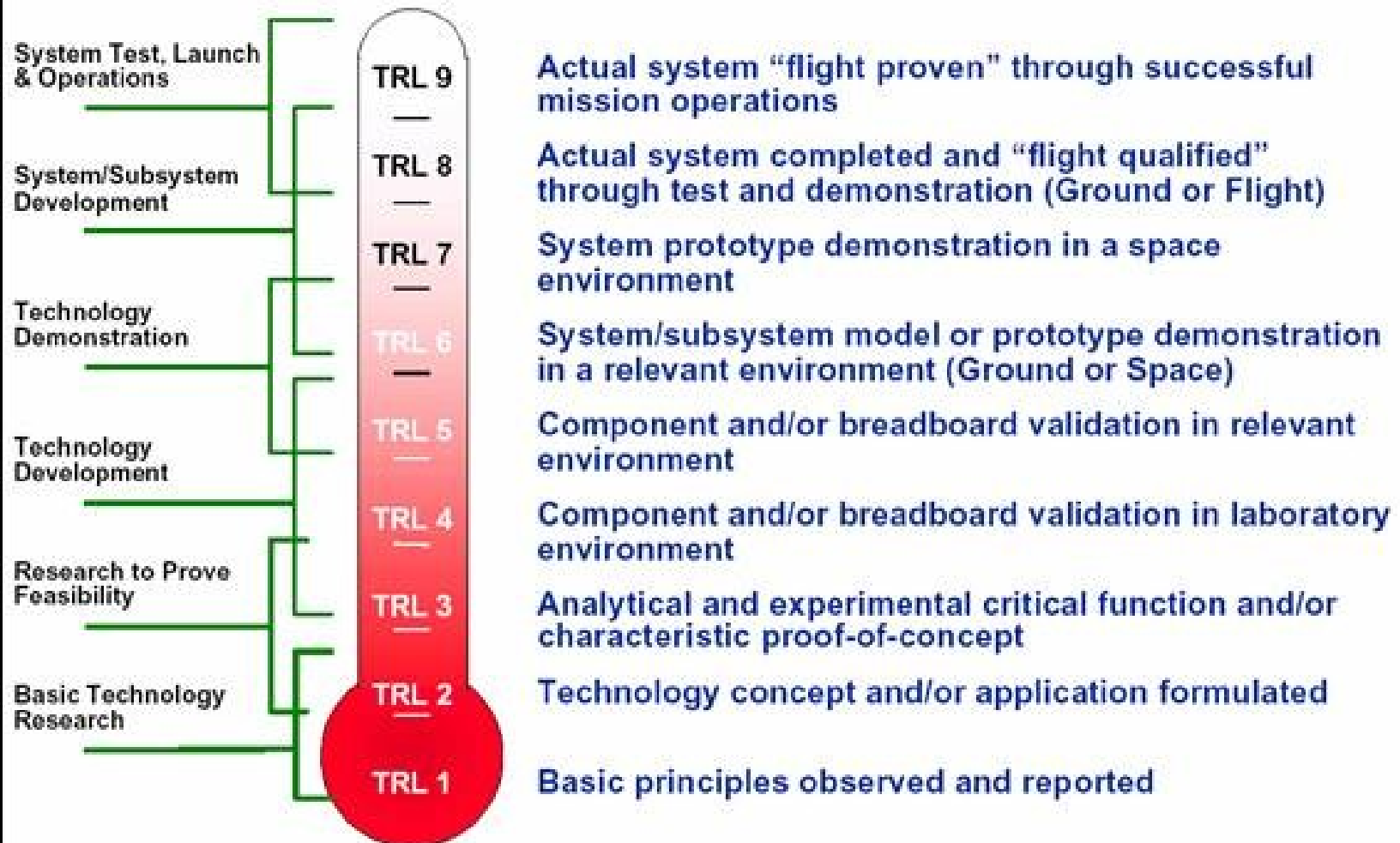
Backup Slides



TRL Definitions NASA



Backup Slides





Evolutionary Acquisition



Backup Slides

INCREMENT 2

INCREMENT 3

OR *Single Step to Full Capability ?*

Key Considerations

- **Urgency of Requirement**
- **Maturity of Key Technologies**
- **Interoperability, Supportability, and Affordability of Alternative Acquisition Approaches**
- **Cost/Benefit of Evolutionary vs. Single Step Approach**



TRL Calculator

Backup Slides

AFRL TRL Calculator Version 1.12

The AFRL Technology Readiness Level (TRL) Calculator measures the level of technical maturity achieved by a technology using the NASA TRL scale. The calculator has separate questions to measure TRL for both Hardware and Software programs. In each category, there are two versions of the calculator. The first asks questions measuring only the technical maturity of the program, and is what we usually mean by TRL. The second adds questions that attempt to measure some program management concerns, such as Customer Focus and Program Documentation. These programmatic concerns define the Program Readiness for Transition (PRT), and usually concern only the government Program Manager (PM).

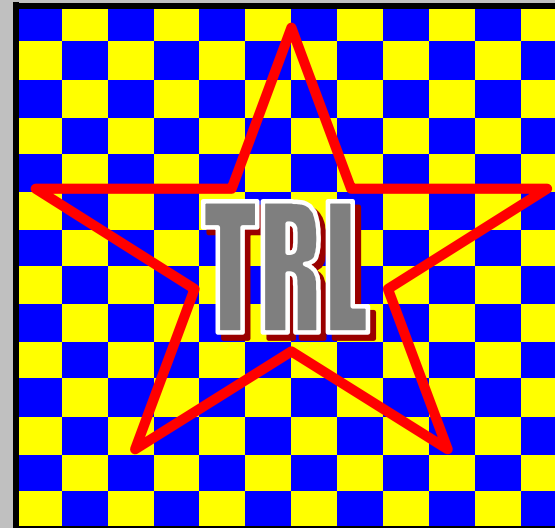
Read the Documentation

Hardware TRL Only

Software TRL Only

Hardware TRL and PRT

Software TRL and PRT





Color Codes

Backup Slides

	You have not documented any task accomplishment at this TRL (PRT) or above.
--	---

	One or more tasks have been accomplished at this TRL (PRT) or above, but there are enough tasks undone so that you probably cannot claim achievement of this TRL (PRT).
--	---

	You have accomplished many of the tasks required for this TRL (PRT), and you may be able to justify achievement of this TRL (PRT) depending on which tasks are still undone.
--	--

	You can justify a claim that your technology program has achieved this TRL (PRT).
--	---

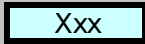
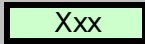
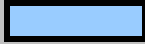
TRL (PRT) Color Codes								1
								2
								3
Throughout this spreadsheet, we have used a consistent color scheme to identify individual TRLs. The overall "flow" of the colors goes from blue to green as the technology's readiness goes from pure research to pure development. Here are the specific colors with the indicated TRL for each:								4
								5
								6
								7
								8
1	2	3	4	5	6	7	8	9



Color Conventions

Other Color Code Conventions

We have tried to use a standard set of cell colors to indicate what the cell contents are, as well as whether or not the cell is available for data entry, etc. We used the spreadsheet's protection feature to preclude altering some cells. Much of the computation is done in hidden cells on the Calculator sheet. The standard color scheme is given below:

	Background, cell isn't used.
	Title of sheet or section. If blank, a decorative border.
	Comments, explanatory material, and instructions.
	Calculator technical maturity (TRL) questions to be answered with check box, radio button, spinner, or slider.
	Calculator programmatic readiness (PRT) questions to be answered with check box, radio button, spinner, or slider. These questions are found on the PRT calculator.
	Data entry by slider bar or spinner. Value isn't high enough to be counted by calculator. On Version sheet, this cell contains the version release date.
	Data entry by slider bar or spinner. Value is high enough to be counted by calculator.
	Data entry by check box or radio buttons.
	Computed or calculated value, no manual data entry permitted.



Definitions



Definitions: DoD 5000.2-R, Appendix 6, April 5, 2002

BREADBOARD:	Integrated components that provide a representation of a system/subsystem and which can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.
"HIGH FIDELITY":	Addresses form, fit and function. High-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.
"LOW FIDELITY":	A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low-fidelity assessments are used to provide trend analysis.
MODEL:	A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.
OPERATIONAL ENVIRONMENT:	Environment that addresses all of the operational requirements and specifications required of the final system to include platform/packaging.
PROTOTYPE:	A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item or system.
RELEVANT ENVIRONMENT:	Testing environment that simulates the key aspects of the operational environment.
SIMULATED OPERATIONAL ENVIRONMENTAL:	Either 1) a real environment that can simulate all of the operational requirements and specifications required of the final system, or 2) a simulated environment that allows for testing of a virtual prototype; used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.



Software TRL Calculator

Not Filled Out



Backup Slides

TRL Calculator Main Menu

Read TRL Documentation

Software TRL Calculator v1.12

▲ % Complete is
▼ now set at:
80%

Technology Readiness Level Achieved									Weighted TRL
1	2	3	4	5	6	7	8	9	

% Complete			Level of Knowledge - Check all that apply or use slider for % complete											
			☐	Know what software needs to do in general terms										
			☐	Have some concept in mind that may be realizable in software										
			☐	Have an idea that captures the basic principles of a possible algorithm										Wgt
◀		▶	☐	Initial analysis shows what major functions need to be done in software										0
◀		▶	☐	Initial analysis gives some idea of what software architecture will look like										
◀		▶	☐	Analysis provides detailed knowledge of specific functions software needs to perform										
◀		▶	☐	Outline of software algorithms available										
◀		▶	☐	Know what software is presently available that does similar task (Inventory completed)										
◀		▶	☐	Know limitations of presently available software (Analysis of current software completed)										
			☐	Know what hardware software will be hosted on										
			☐	Know what output devices are available										
◀		▶	☐	Inventory of external interfaces completed										
◀		▶	☐	Analysis of internal interface requirements completed										
◀		▶	☐	Analysis of timing constraints completed										
◀		▶	☐	Analysis of data requirements and formats completed										
◀		▶	☐	Analysis of database structures and interfaces completed										
◀		▶	☐	External interfaces described as to source, format, structure, content, and method of support										

% Complete		Software Function Development - Check all that apply or use slider for % complete												
◀	▶	☐	Software architecture defined in terms of major functions to be performed											
◀	▶	☐	Preliminary algorithm development completed											
◀	▶	☐	Software programming language selected										Wgt	
◀	▶	☐	Algorithms converted to pseudocode										0	
◀	▶	☐	Formal software test/inspection protocol defined											
◀	▶	☐	Coding of individual functions/modules completed											
◀	▶	☐	Requirements for each function established											



Software TRL Calculator

Not Filled Out



Backup Slides

% Complete		Software Integration and Configuration Management - Check all that apply or use slider		
◀	▶	☐	Existing software examined for possible reuse	
◀	▶	☐	Functions integrated into modules	
		☐	"Alpha" version software has been released	Wgt
		☐	"Beta" version software has been released	0

% Complete		Testing - Check all that apply or use slider for % complete		
◀	▶	☐	Individual functions tested to verify that they work	
◀	▶	☐	Individual modules tested to verify that the module components (functions) work together	
◀	▶	☐	Individual modules and functions tested for bugs	Wgt
◀	▶	☐	Metrics established	0
◀	▶	☐	Each software/system interface tested individually under stressed and anomolous conditions	
◀	▶	☐	Designs verified through formal inspection process	
◀	▶	☐	Verification, Validation and Accreditation (VV&A) initiated	
◀	▶	☐	VV&A in process with the verification step that software specifications are met completed	
◀	▶	☐	VV&A validation step completed, software works in real world	
◀	▶	☐	VV&A accreditation step completed, software authorized for use in intended weapon system	
◀	▶	☐	DT&E completed, software meets specifications	
◀	▶	☐	OT&E completed, software system is operational	

Environment - Choose the best statement		
☐	"Back-of-the-envelope" concept	
☐	Desktop environment	
☐	Academic environment	
☐	Individual functions or modules demonstrated in a laboratory environment	Wgt
☐	Integration of modules/functions demonstrated in a laboratory environment	0
☐	Representative software system or prototype demonstrated in a laboratory environment	
☐	Fully integrated software prototype demonstrated in actual or simulated operational environment	
☐	Software qualified through test and evaluation in actual system (DT&E completed)	
☐	Actual mission software "flight proven" through successful mission operations (OT&E completed)	



PRT Calculator

S&T Program in Early Development



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Read TRL Documentation

TRL Calculator

Hardware PRT Calculator v 1.12									
Program's Readiness for Transition						2	1		Weighted PRT
1	2	3	4	5	6	Note that the PRT above is never greater than the TRL.			

▲ % complete is now set at
▼ 80%

% Complete	Level of Knowledge (Check all that apply or use slider for % complete)		
◀ ▶	☒	Initial observations reported in scientific journals/conference proceedings/technical reports	
◀ ▶	☐	Analytical studies reported in scientific journals/conference proceedings/technical reports	
◀ ▶	☐	Laboratory requirements derived from system requirements are established	Wgt
◀ ▶	☐	System requirements flow down through work breakdown structure (systems engineering begins)	0
◀ ▶	☐	S&T exit criteria established	PRT 1

% Complete	Customer Focus (Check all that apply or use slider for % complete)		
◀ ▶	☒	Customer identified	
◀ ▶	☐	Customer expresses interest in application	
◀ ▶	☐	Customer participates in requirements generation	
◀ ▶	☐	Customer publishes requirements document	Wgt
◀ ▶	☐	Customer representative is member of Integrated Product Team (IPT)	0
◀ ▶	☐	Customer identifies transition window(s) of opportunity	PRT 2
◀ ▶	☐	Customer commits to transition through ATD commissioning and/or MOU	
◀ ▶	☐	Customer commits to transition via POM process	

% Complete	Program Documentation (Check all that apply or use slider for % complete)		
◀ ▶	☒	Investment Strategy Sheet	
◀ ▶	☐	Draft Systems Engineering Master Plan (SEMP)	
◀ ▶	☐	Draft Test & Evaluation Master Plan (TEMP)	
◀ ▶	☐	Final Systems Engineering Master Plan (SEMP)	Wgt
◀ ▶	☐	Final Test & Evaluation Master Plan (TEMP)	0
◀ ▶	☐	Draft Transition Plan with Business Case (e.g., ATCTC Document)	PRT 2
◀ ▶	☐	Final Transition Plan with Business Case	
◀ ▶	☐	Science and Technology Exit Criteria	
◀ ▶	☐	Final Technical Report	



TRL Calculator

S&T Program Ready to Transition



Backup Slides

System Integration (Pick the best answer)	
☐	No attempt at integration; still trying to see whether individual parts of the technology work
☐	Paper studies indicate that system components ought to work together
☐	Laboratory experiments with available components show that they work together (lab kludge)
☐	Available components assembled into system breadboard
☐	Interfaces between components/subsystems are realistic (Breadboard with realistic interfaces)
☐	Fidelity of system mock-up improves from breadboard to brassboard
☒	Laboratory system is high-fidelity functional prototype of operational system
☐	Prototype improves to pre-production quality
☐	System is form, fit, and function design for intended application and weapon system platform
☐	System has been installed and deployed in intended weapon system platform

Wgt
0
TRL 6

% Complete	Modeling and Simulation (Check all that apply or use slider for % complete)
☐	☒ M&S used to verify physical principles
☐	☒ M&S used to complement laboratory experiments
☐	☐ M&S used to simulate some components and interfaces between components
☐	☒ M&S used to simulate system performance in an operational environment
☐	☐ M&S used to simulate some unavailable elements of system, but these instances are rare

Wgt
0
TRL 5

% Complete	Testing (Check all that apply or use slider for % complete)
☐	☒ Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
☐	☒ Factory acceptance testing of laboratory system in laboratory setting
☐	☒ Operational/flight testing of laboratory system in representational environment
☐	☐ DT&E demonstrates that system meets procurement specifications
☐	☐ OT&E demonstrates that system is capable of performing mission requirements

Wgt
0
TRL 7

Environment (Pick the best answer)	
☐	"Back of envelope" environment
☐	Desktop environment
☐	Academic environment
☐	Controlled laboratory environment
☐	Laboratory environment modified to approximate operational environment
☐	Realistic environment outside the lab, but not the eventual operating environment
☒	Operational environment, but not the eventual platform, e.g., test-bed aircraft
☐	Form, fit, and function demonstrated in eventual platform/weapon system
☐	Operational missions performed in actual platform/weapon system

Wgt
0
TRL 7